# CHAPTER 3
# THE STRUCTURE OF MATTER

## CENTURIES OF DISCOVERY

Greek Atom
- *Atomos* means indivisible
- *Four Substances:* earth, water, air, & fire
- *Four Essences:* wet, dry, hot, & cold

Substances/Elements
- 112 identified
- 92 naturally occurring
- 20 artificially produced

***An atom is the smallest particle that has all the properties of an element!***

Subatomic Particles
- Particles smaller than atom

Dalton Atom
- Hook-and-eye affair

John Dalton (1808)
- He showed that elements could be classified according to integral values of atomic mass

Dmitri Mendeleev
- First periodic table of elements

Alkali Metals
- Group 1 elements
- All soft metals that combine readily with oxygen & react violently with water

Halogens
- Group VII elements
- Easily vaporized & combine with metals to form water-soluble salts

Noble Gas
- Group VIII elements
- Highly resistant to reaction with other elements

Thomson Atom
- Plum pudding
- *Plum:* negative electric charges (electrons)
- *Pudding:* a shapeless mass of positive electrification

J.J. Thomson (1890)
- He investigated the physical properties of cathode rays (*electrons*)
- He concluded that electrons were integral parts of all atoms

Ernest Rutherford (1911)
- Nuclear model
- He disproved Thomson's model
- He described the atom as containing a small, dense, positively charged center surrounded by a negative cloud of electrons
- He called the center of the atom the *nucleus*

Bohr Atom (1913)
- Miniature solar system
- He improved Rutherford's description of the atom
- The electrons revolved about the nucleus in prescribed orbits or energy levels

Quantum-chromodynamics (QCD)
- More accurately described the details of atomic structure

## FUNDAMENTAL PARTICLES

Particle Accelerator
- Atom smasher
- It is used in mapping the structure of atomic nucleus

Nucleons
- Protons (+) & neutrons (O)
- It is composed of quarks & gluons (subatomic particles)

***The fundamental particles of an atom are the electron, proton & the neutron!***

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Electron
- *Location:* orbital shells
- *Relative:* 1
- *Mass in kg:* $9.1 \times 10^{-31}$
- *Mass in amu:* 0.000549
- *Number:* 0
- *Charge:* -1
- *Symbol:* -

Proton
- *Location:* nucleus
- *Relative:* 1836
- *Mass in kg:* $1.673 \times 10^{-27}$
- *Mass in amu:* 1.00728
- *Number:* 1
- *Charge:* 1
- *Symbol:* +

Neutron
- *Location:* nucleus
- *Relative:* 1838
- *Mass in kg:* $1.675 \times 10^{-27}$
- *Mass in amu:* 1.00867
- *Number:* 1
- *Charge:* 0
- *Symbol:* O

Atomic Mass Unit
- The mass of a neutral atom of an element
- *Symbol:* amu
- *1 amu:* ½ the mass of a carbon-12 atom

Atomic Mass Number
- Number of protons plus number of neutrons in the nucleus
- *Symbol:* A
- *Formula:* protons + neutrons

## ATOMIC STRUCTURE

***The atom is essentially empty space!***

Neutral Atom
- Same number of electrons & protons

Number of Protons
- Determine the chemical behavior of an atom
- Determine the chemical element

Isotopes
- Same number of protons, but different number of neutrons

***In their normal state, atoms are electrically neutral; the electric charge on the atom is zero!***

Electron Arrangement
- The number of electrons in the outermost shell of an atom = group in the periodic table & determines the valence of an atom
- The number of outermost electron shell of an atom = period in the periodic table

Maximum Electrons Per Shell
- *Formula:* $2n^2$

Principal Quantum Number
- The shell number (n)

***No outer shell can contain more than eight electrons!***

Orderly Scheme of Atomic Progression
- Interrupted in fourth period

Transitional elements
- Atoms associated with the phenomenon mentioned above

Centripetal Force
- Center-seeking force
- The force that keeps an electron in orbit

Centrifugal Force
- Flying-out-from-the-center force
- The force that causes an electron to travel straight and leave the atom

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Electron Binding Energy
- The strength of attachment of an electron to the nucleus
- *Symbol:* $E_b$

Tungsten (W-74) & Molybdenum (Mo-42)
- The primary constituents of x-ray tube target

Barium (Ba-56) & Iodine (I-53)
- Radiographic & fluoroscopic contrast agents

Carbon (C-6)
- The important component of human tissue

Ionization Potential
- The amount of energy (*34 keV*) necessary to ionize tissue atoms

## ATOMIC NOMENCLATURE

Chemical Symbols
- The alphabetic abbreviations of an element

Number & Arrangement of Electrons
- It determines the chemical properties of an element

Atomic number
- Number of Protons
- *Symbol:* Z

Atomic Mass Number
- Number protons plus number of neutrons
- *Symbol:* A

***The atomic number & the precise mass of an atom are not equal!***

Carbon-12 Atom
- Its A & Z are equal
- *Rationale:* it is the arbitrary standard for atomic measure

Elemental Mass
- It is determined by the relative abundance of isotopes & their respective atomic masses

Protocol for Representing Elements in a Molecule
- *Upper Left*: atomic mass (A)
- *Lower Left:* atomic number (Z)
- *Upper Right:* valence state (+/-)
- *Lower Right:* number of atoms/molecules

**CHARACTERISTICS OF SOME ELEMENTS IMPORTANT TO RADIOLOGIC SCIENCE**

| Element | Chemical Symbol | Z | A | Naturally Occurring Isotopes |
|---|---|---|---|---|
| Beryllium | Be | 4 | 9 | 1 |
| Carbon | C | 6 | 12 | 3 |
| Oxygen | O | 8 | 16 | 3 |
| Aluminum | Al | 13 | 27 | 1 |
| Calcium | Ca | 20 | 40 | 6 |
| Iron | Fe | 26 | 56 | 4 |
| Copper | Cu | 29 | 63 | 2 |
| Molybdenum | Mo | 42 | 98 | 7 |
| Ruthenium | Ru | 44 | 102 | 7 |
| Rhodium | Rh | 45 | 103 | 5 |
| Silver | Ag | 47 | 107 | 2 |
| Tin | Sn | 50 | 120 | 10 |
| Iodine | I | 53 | 127 | 1 |
| Barium | Ba | 56 | 138 | 7 |
| Tungsten | W | 74 | 184 | 5 |
| Rhenium | Re | 75 | 186 | 2 |
| Gold | Au | 79 | 197 | 1 |
| Lead | Pb | 80 | 208 | 4 |
| Uranium | U | 92 | 238 | 3 |

**CHARACTERISTICS OF VARIOUS NUCLEAR ARRANGEMENTS**

| Arrangement | Atomic Number | Atomic Mass Number | Neutron Number |
|---|---|---|---|
| Isotope | same | different | different |
| Isobar | different | same | different |
| Isotone | different | different | same |
| Isomer | same | same | same |

Technetium-99m (Tc-43)
- It decays to technetium-99
- *Energy Emitted:*140 keV gamma rays

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## COMBINATIONS OF ATOMS

Molecules
- The group of atoms of various elements
- The smallest unit of a compound

Sodium chloride (NaCl)
- Common table salt

Chemical Compound
- Any quantity of one type of molecule

CHON (C-6, H-1, O-8, N-7)
- Carbon, Hydrogen, Oxygen, Nitrogen
- 90% of the human body

Water
- 80% of the human body

Covalent Bond
- The chemical union between atoms formed by sharing one or more pairs of electrons
- *Example:* $H_2O$

Ionic Bond
- The bonding that occurs because of an electrostatic force between ions
- *Example:* NaCl

Sodium bicarbonate ($NaHCO_3$)
- Baking soda

***The smallest particle of an element is an atom; the smallest particle of a compound is a molecule!***

## RADIOACTIVITY

Radioactivity
- The emission of particles & energy in order to become stable

Radioactive Decay/Radioactive Disintegration
- The process by which the nucleus spontaneously emits particles & energy & transforms itself into another atom to reach stability
- It occurs when the nucleus contains too few or too many neutrons

Radioisotopes
- Radioactive atoms that have the same number of protons

Uranium (U-92) & Carbon-14
- Two primary source of naturally occurring radioisotopes

Beta Emission
- It occurs in all radioisotopes
- It occurs more frequently than alpha emission
- *Results:*
  - Loss of small quantity of mass & one unit of negative electric charge
  - To increase the Z by one while A remains the same
  - Changing of an atom from one type of element to another
- Neutron undergoes conversion to a proton

Alpha Emission
- It occurs only in heavy radioisotopes
- It is much more violent process
- It is consists of 2 protons & 2 neutrons
- *Atomic Mass Number:* 4
- *Results:*
  - Nucleus loses 2 units of positive charge & 4 units of mass
  - Chemically different atom & an atom lighter than 4 amu

Radioactive Half-life
- The time required for a quantity of radioactivity to be reduced to one-half its original value
- *Symbol:* $T_{1/2}$
- *I-131:* $T_{1/2}$ = 8 days
- *C-14*: $T_{1/2}$ = 5730 days

Radioactive Decay Law
- It described the rate of radioactive decay & the quantity of material present at any given time
- *Formula:* Activity Remaining = Original Activity $(0.5)^n$
- *n:* number of half lives

## TYPES OF IONIZING RADIATION

Five Physical Characteristics
- Mass, Energy, Velocity, Charge & Origin

Particulate Radiation
- It has finite range in matter
- *Examples:* alpha & beta Particles

Alpha Particle
- Equivalent to a helium nucleus
- It contains 2 protons & 2 neutrons
- *Symbol:* $\alpha$
- *Mass:* 4 amu
- *Charge:* +2
- *Origin:* nucleus of heavy radioactive nuclei
- *Energy:* 4-7 MeV
- *Range:* 1-10 cm (air); <0.1 mm (soft tissue)
- *Ionization Rate:* 40,000 atoms/cm

Beta Particle
- Light particles
- *Symbol:* $\beta^-$ or $\beta^+$
- *Mass:* 0 amu
- *Charge:* -1 or +1
- *Origin:* nucleus of radioactive nuclei
- *Energy:* 0-7 MeV
- *Range:* 10-100 cm (air); 1-2 cm (soft tissue)
- *Ionization Rate:* several hundred of atoms/cm

Negative Beta Particles
- The same with electrons, they only differ in origin

Positive Beta Particles
- The same mass with electrons
- Positrons
- Antimatter

Electromagnetic Radiation
- *Examples:* x-rays & gamma rays
- They only differ in origin
- It is often called *photons*
- It has unlimited range in matter

Photons
- No mass & no charge
- Travel at the speed of light (c)
- *c:* $3 \times 10^8$ m/s or $1.86 \times 10^5$ mi/s

***X-rays and gamma rays are the only forms of ionizing electromagnetic radiation of radiologic interest!***

X-rays
- *Symbol*: X
- *Mass:* 0
- *Charge:* 0
- *Origin:* electron cloud
- *Energy:* 0-25 MeV
- *Range:* 0-100 m (air); 0-30 cm (soft tissue)
- *Ionization Rate:* 100 ip/cm (equal to beta particles)

Gamma Rays
- *Symbol:* $\gamma$
- *Mass:* 0
- *Charge:* 0
- *Origin:* nucleus/radioactive nuclei
- *Energy:* 0-5 MeV
- *Range:* 0-100 m (air); 0-30 cm (soft tissue)
- *Ionization Rate:* 100 ip/cm (equal to beta particles)

Nonionizing Radiation
- A type of radiation used in UTZ & MRI